Art. XXI.—*Field Practice with the Aneroid Barometer.*

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This instrument measures the pressure of the atmosphere by means of an exhausted metallic chamber kept from collapsing by a powerful spring, the motion under varying pressures being magnified by a delicate lever system so as to become easily visible. It constitutes a cheap and portable substitute for the more perfect mercurial barometer, and is subject to the same limitations and also to special defects of its own, which, if not allowed for, render its indications comparatively unreliable. With proper care, however, in choosing, testing and using, it is sufficiently accurate for many purposes connected with exploration, surveying and engineering, and vastly more convenient than the cumbrous, fragile and costly mercurial barometer. Extreme differences of opinion have existed amongst experts as to the aneroid, some regarding it as hopelessly unreliable, while others quote examples of astonishingly accurate work done by its means. As is not uncommon in other cases the truth lies between these extremes. The former view is the natural result of neglecting to test the instrument and allow for its errors, which may involve hundreds of feet difference of level, even in good instruments, and which vary enormously in individual cases. For example, a certain aneroid tested at the University gave at one part of its range 1200 feet difference of level, when it ought to have given only 1000. Another tested at the same time was almost as perfect as a mercurial at that particular part of its scale, but had an error of 100 feet in 500 at another place. Both these instruments were used most successfully in the field, when these errors were known and allowed for, which without this knowledge would have been almost useless. On the other hand, the extraordinarily accurate results sometimes quoted for aneroid levelling are no doubt due to good fortune, and the tendency to recollect and quote the successful and forget the unsuccessful instances. As the result of a fairly large experience, it may be laid down that, to determine differences of level up to 100 feet, within 5 feet of the truth, up to 1000 feet within 10 feet, and greater altitudes within 1 per cent. of their total amount, is excellent work, while errors of twice the above amount will mark a fair average performance.

Choice of Instrument.

Neither appearance nor cost is reliable evidence of quality—cheap and rough-looking aneroids have sometimes performed admirably; costly and apparently highly-finished ones, owing to hidden defects, the reverse. The name of a good maker is some guarantee, but should not be too much relied on. Some aneroids are made very small; while admitting that diminutive instruments *may be* accurate, it is a safer course to avoid them, and prefer those with a dial not less than 2 inches diameter. In them the mechanism is more easily made delicate enough and the larger dial shows small differences of pressure more clearly. Instruments with dials 4 or 5 inches diameter are better still, but are costly and rather cumbersome to carry. Whether the face is open, showing the mechanism or not, is immaterial. Some aneroids profess to be compensated against changes of temperature, others do not. In the first case, too much reliance should not be placed on the accuracy of the compensation, for at best it is rather rough; in the latter the instrument should be carefully tested at different temperatures, and a table of temperature corrections drawn up and applied to the readings. The best way is to work only when the weather is neither extremely warm nor cold, and to keep the instrument in an inner pocket, when it will approach to the temperature of the body.

Testing the Instrument.

Every instrument when purchased should be carefully tested in the vacuum chamber, and this test should be repeated if possible every six months. Should the instrument fall or receive a severe knock, it should at once be re-tested as its table of corrections may be modified. The vacuum chamber may be exhausted by a water jet aspirator, or by a mechanical air pump, and the degree of exhaustion is determined by a mercurial or water barometer, the upper end of which communicates with the vacuum chamber. A water barometer 8 feet high is sufficient for the State of Victoria, where altitudes of over 6000 feet are rare.

In testing, the aneroid should be placed in the chamber, and the pressure slowly reduced by half-an-inch of mercury each time till the limit is reached. Then the pressure should be slowly increased by half-an-inch of mercury each time till atmospheric pressure is regained. This should be done as near the sea level as possible, and preferably when the barometer is high, otherwise, possibly, part of the range of the aneroid, and that a most important part, may remain un-tested. While in the chamber, the instrument should be most carefully watched, and its readings noted accurately. It is of vital importance that the index move smoothly and without any sticking or jerking, and that the indications be exactly the same with reducing as with increasing pressure. Friction, and especially irregular friction, of the multiplying mechanism, is a most fatal defect in an aneroid. A gentle tapping or scratching with the thumb nail will set up vibration, and so diminish friction. This is generally used in the field, and some appliance for enabling it to be done in the vacuum chamber is desirable. The readings at every half-inch of mercury having been taken and compared with the barometer, a table, or better still a diagram, of corrections should be made, and used to correct all readings taken in the field.

In the absence of a vacuum chamber, a fairly good test may be made on a railway that rises rapidly, and has numerous stations at known levels. The railway from Penrith to Katoomba, in New South Wales, which rises over 3000 feet in 30 miles, would answer well. The rack railways, now so common in Switzerland and other mountainous countries, which rise several thousand feet in a few miles, would be better still. By repeating the test with varying barometric pressures, about 1000 feet more of the range of the instrument may be verified. The same thing may be done for a small part of the range in a tall building such as the Eiffel Tower at Paris, or even the tall business premises existing in Melbourne. The height of the building is best measured by a steel tape line, but by counting the steps of the staircases and measuring the height of a step, a very fair approximation may be obtained.

In these cases the proper difference of reading is computed from the height by means of the appropriate tables, and the actual difference by aneroid being compared therewith, the correction is obtained. It is to be noted that the actual magnitude of the corrections is of no importance. All that is necessary is that they should be accurately known. It is a convenience to have them all additive. If they are not so, they may often be made so by turning the adjusting screw at the back of the instrument.

Using the Aneroid.

As some instruments otherwise good vary their reading considerably according to the position in which they are held, it is well always to read with the dial horizontal. A lens may be used, and in any case, to avoid parallax, try to look at right angles to the dial. A mirror dial, as applied to some electrical instruments, would be theoretically perfect, for when the index covered its reflection, there would be no parallax. A small metal flag is sometimes put at the end of the index, and this, by becoming invisible, shows that the line of sight is perpendicular. The ordinary index, however, if it works fairly close to the dial, and is read carefully, will give very good results. If a very rapid ascent or descent of several hundred feet is made, it is well to give the instrument a few minutes' rest before reading it, as it does not always immediately adapt itself to a large change of pressure. For the same reason, testing in the vacuum chamber should be performed slowly, and a pause of a minute, at least, made at each point of comparison. For good work it is suggested that two aneroids and a barograph, or self-recording aneroid, be employed. This instrument should, if possible, be tested in the vacuum chamber as are the aneroids. It is not so important, however, to do this, as the range of the barograph is much smaller than of the aneroids, and the risk of error consequently less. The barograph is left at the starting or datum point, and shows every variation of atmospheric pressure there. This is better than trusting to a cook or camp keeper, who may be unskilful or negligent in reading the instrument left with him. The two aneroids, by the substantial agreement of their corrected readings, will give asssurance that both are working well, while a marked difference will show that something is wrong, and lead to further investigation. Each reading is booked, and the time by the watch noted, so that the corresponding barograph reading may be ascertained. On leaving and on returning to camp, the aneroids and barograph should be compared together, and any small inconsistency noted and distributed over the observations.

Thermometer readings should also be taken at the camp and at the aneroid stations, but these need not be nearly so precise as the aneroid readings. If expense is no object, a thermograph, or self-recording thermometer, may be kept at the camp or starting point, as well as a barograph, but this is rarely necessary. Every opportunity that presents itself of comparing the aneroid with a good mercurial barometer should be taken advantage of as a check.

Reducing the Observations and Computing the Altitudes.

Many formulae and tables have been published for this purpose, but most of them are needlessly cumbrous. There is no need of computing decimals of a foot when the instrument will not indicate anything less than 10 feet, or 5 feet at the very closest, and when continual atmospheric variations affect the result by several feet in perhaps a few minutes of time. The same may be said of such theoretical refinements as correction for the variation of gravity due to latitude or altitude.

Table I.

The following table, founded on those of Laplace and Guyot, is recommended for use in Victoria:—

Inches of Mercury.	Feet.	Difference.	Inches of Mercury.	Feet.	Difference.
23.5	0		24.8	1406	
		111			105
6	111		9	1511	
		110			105
7	221		25.0	1616	
		110			105
8	331		1	1721	
		110			104
9	441		2	1825	
		109			103
24.0	550		3	1928	
		109			103
1	659		4	2031	
		108			103
2	767		5	2134	
		108			102
3	875		6	2236	
		107			102
4	982		7	2338	
		107			101
5	1089		8	2439	
		107			101
6	1196		9	2540	
		105			101
7	1301		26.0	2641	
		105			100

Inches of Mercury.	Feet.	Difference.	Inches of Mercury.	Feet.	Difference.
26.1	2741	100	28.6	5131	91
2	2841	100	7	5222	91
3	2941	99	8	5313	91
4	3040	99	9	5404	90
5	3139	98	29.0	5494	90
6	3237	98	1	5584	90
7	3335	98	2	5674	89
8	3433	97	3	5763	89
9	3530	97	4	5852	89
27.0	3627	97	5	5941	88
1	3724	96	6	6029	88
2	3820	96	7	6117	88
3	3916	95	8	6205	88
4	4011	95	9	6293	87
5	4106	95	30.0	6380	87
6	4201	95	1	6467	87
7	4296	94	2	6554	86
8	4390	94	3	6640	86
9	4484	93	4	6726	86
28.0	4577	93	5	6812	85
1	4670	93	6	6897	85
2	4763	93	7	6982	85
3	4856	92	8	7067	85
4	4948	92	9	7152	84
5	5040	91	31.0	7236	

By taking the difference of the figures in the second column of the preceding Table, opposite the two readings found in the first column, the difference in altitude of the two points is found. But this Table is correct only where the average temperature of the air is 32° F. For any higher temperature the result must be increased in the subjoined ratio.

TABLE II.

Temperature.	Multiplier.	Temperature.	Multiplier.
32°	1.00	68°	1.08
37°	1.01	72°	1.09
41°	1.02	77°	1.10
46°	1.03	81°	1.11
50°	1.04	86°	1.12
54°	1.05	90°	1.13
59°	1.06	95°	1.14
63°	1.07	100°	1.15

EXAMPLE.

Reading at lower station - -	28.61	
Instrumental correction - -	.04	
	28.65	
Corresponding number from Table I. -		$5131 + \frac{5}{10} 91 = 5176$
Reading at upper station - -	26.78	
Instrumental correction - -	.06	
	26.84	
Corresponding number from Table I. -		$3433 + \frac{4}{10} 97 = 3472$
Difference - - -		1704

Average temperature of intermediate air 60° F.

Multiplier from Table II. 1.062. $1704 \times 1.062 = 1809.6$ feet.

The same example worked out from Guyot's Tables, which are much more voluminous than the preceding, gave 1810.3 as the result, or about 8 inches more. It is not too much to state that no aneroid in existence could be depended upon to give this height by a single pair of observations within several feet of the truth. Thus this discrepancy is seen to be absolutely unimportant.

Easier but Rougher Methods.

Where less precision is needed the following rule may be used. Taking the average temperature of the air as 50° F. in ordinary winter, and 77° F. in ordinary summer weather.

	For each $\frac{1}{100}$ inch allow	
	In Winter.	In Summer.
From 31 to 30 inches	8.9 ft.	9.4 ft.
,, 30 ,, 29 ,,	9.2 ,,	9.8 ,,
,, 29 ,, 28 ,,	9.5 ,,	10.1 ,,
,, 28 ,, 27 ,,	9.9 ,,	10.4 ,,
,, 27 ,, 26 ,,	10.2 ,,	10.8 ,,

In spring or autumn the mean of the summer and winter results may be taken.

To put it another way a difference of readings of 30 to 29 inches represents 1000 feet at a temperature of 88° Fahrenheit, 950 feet at 62°, and 900 feet at 40°; 29 to 28 inches represents 1000 feet at 75°, 950 feet at 50°, and 900 feet at 25°; 28 to 27 inches represents 1000 feet at 54°, and 950 feet at 32°.

A still quicker and easier way is to allow 10 feet for each $\frac{1}{100}$ inch of mercury in summer, and $9\frac{1}{2}$ feet in winter for all heights up to 3000 feet above sea. This will usually give results within about 3 or 4 per cent. of the truth.

Examples of Successful Work.

1. In a building, an aneroid was carried upstairs and read at several known levels. It was then carried down and read a second time at each level. From the mean readings the heights were computed as below:—

By aneroid	6.7	19.2	35.5	69
By actual measurement	8.8	23.8	37.5	66.6

2. Four readings were taken, at intervals of several hours, at a point on the Geelong Waterworks, the level of which was accurately known, and compared with simultaneous readings at the Melbourne Observatory, 40 miles distant. The true difference of level was 760 feet, and the aneroid results varied from

752 to 756 feet. The intervening country was comparatively level and open.

3. A barograph was left at Croydon Railway Station. Three aneroids were taken to the top of Mount Dandenong, six miles distant, and nearly 1700 feet higher. Each aneroid was read nine times, beginning at 10.30 a.m., and ending at 4 p.m., and the height of the mountain computed, taking Croydon as the datum point. The three aneroids gave 2064, 2057, and 2046 feet respectively, above sea level, while the trigonometrical survey height on the large Government map of Victoria is 2060.

4. A barograph was left at Moe Railway Station. Three aneroids were taken to a point on Mount Baw Baw, 25 miles to the north, and about 5000 feet above Moe, and read once only, as the party had to return immediately. The results on being worked out gave 5235, 5301, and 5258 feet above sea respectively, for the three instruments. On a subsequent occasion a party camped for several days at the same place and made hourly readings of two good mercurial barometers, the results of which gave 5200.

5. The instrument mentioned in example 2 was taken by railway from Sydney to Brisbane, 720 miles, over country rising at one point 4500 feet above sea, and agreed throughout with the railway levels within 3 per cent. It was also taken by railway from Durban to Capetown, in South Africa, *viâ* Pretoria, a distance of fully 1500 miles, the country rising in parts to over 5000 feet above sea, and give the heights of the railway stations within 5 per cent. of the truth. These results should answer doubts that have been expressed as to the utility of aneroid levelling in extensive explorations.

General Recommendations.

Properly tested aneroids, used with judgment and suitable precautions, are capable of doing very useful work, but too much must not be expected from them. They should be used in conjunction with a barograph placed preferably at a railway station or other point, the level of which is accurately known. From such a point as a centre, it is possible to do fairly good work for a radius of say 20 miles in open country, and 10 miles in rangy country. If it is necessary to go further than this from known levels, new datum points should be established, and connected by a series of repeated observations with the railway station or other known point. Aneroid work should not be attempted in stormy weather, or when atmospheric conditions are specially unsettled, nor in extremely hot or extremely cold weather.

Should the expense not be too great, it would be well to have two barographs placed at two points in the district surveyed, as far apart in distance and at as great a difference of elevation as is conveniently attainable, and take the mean of the two as giving the true variation of pressure. There should in many cases be no insuperable difficulty in doing this, as a decent barograph may be purchased for £5, and it will need attention but once a week. If any meteorological station exists within say 50 miles of the work in open, or 25 miles in rangy conntry, the readings obtained there should be used as far as possible as a check on the barograph. If no such station be available, it will conduce to accuracy to have a mercurial barometer or boiling-point hypsometrical apparatus at the barograph station, and check both barograph and aneroid by its means as often as convenient. A comparison every week is suggested as a minimum. The mercurial barometer or boiling-point apparatus might be occasionally taken out in the field as a check on the aneroids there. This, however, would probably only be done for specially important points, such as new barograph stations, as it would involve considerable extra labour. Narrow and deep valleys are bad as barograph stations, as in them the pressure varies with the temperature in such a way as to make the station appear too high in the day time and too low at night. The barograph will read correctly only at say 9 a.m. and 2 p.m.

Ranges of mountains act as atmospheric dams, causing the pressure at the same level on the two sides to vary by amounts corresponding to 50 or even 100 feet difference of altitude. Hence, on passing such a range, new datum points of known level should be sought.

In reducing aneroid observations taken on a long journey or exploration, the simultaneous readings at stations of known level should be taken into account. For example, in reducing observations taken during a journey across Australia, the isobaric charts published by the Observatory would give the probable sea-level reading at each point, from which and the actual reading the height is determined. Work of this sort, however, though by no means without value, cannot possibly approach in precision that done under more favourable conditions.

In compiling the above notes, use has been made of Bulletin No. 8 of the Department of Mines of Victoria, by Professor Gregory, F.R.S., and valuable hints have been received from Mr. T. W. Fowler, M.C.E., Lecturer on Surveying, Melbourne University. To these gentlemen thanks are accordingly given.

Note.—Whymper and others have called attention to the mechanical hysteresis, or fatigue of the aneroid spring, as a source of serious error, and a special instrument has been devised to obviate it. This trouble, which was serious at high altitudes in the Andes, does not appear to be of practical importance on the very moderate elevations found in Australia.

An aneroid with optical instead of mechanical magnification has been brought out by Goldschmidt, to eliminate friction errors, but, so far, does not appear to have gained much favour.